



# The CDF-II Tau Physics Program - Triggers, $\tau$ ID and Preliminary Results

S. Baroiant, M. Chertok, M. Goncharov, T. Kamon, V. Khotilovich, R. Lander, T. Ogawa, C. Pagliarone, F. Ratnikov, A. Safonov, et al.

## ► To cite this version:

S. Baroiant, M. Chertok, M. Goncharov, T. Kamon, V. Khotilovich, et al.. The CDF-II Tau Physics Program - Triggers,  $\tau$  ID and Preliminary Results. 2007. in2p3-00122554

**HAL Id: in2p3-00122554**

**<https://hal.in2p3.fr/in2p3-00122554>**

Preprint submitted on 3 Jan 2007

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# The CDF-II Tau Physics Program Triggers, $\tau$ ID and Preliminary Results

S. Baroiant<sup>1</sup>, M. Chertok<sup>1</sup>, M. Goncharov<sup>2</sup>, T. Kamon<sup>2</sup>, V. Khotilovich<sup>2</sup>,  
R. Lander<sup>1</sup>, T. Ogawa<sup>3</sup>, C. Pagliarone<sup>4</sup>, F. Ratnikov<sup>5</sup>, A. Safonov<sup>1</sup>,  
A. Savoy-Navarro<sup>6</sup>, J.R. Smith<sup>1</sup>, E. Vataga<sup>4</sup>

(For the CDF-II Collaboration)

UDC preprint  
© 2003

<sup>1</sup>University of California, Davis  
(Davis, California, 95616 - USA),

<sup>2</sup>Texas A&M University  
(College Station, Texas 79409 - USA),

<sup>3</sup>Waseda University  
(169-8555 Tokyo - Japan)

<sup>4</sup>INFN Pisa  
(via F.Buonarroti, 2 - 56100 PISA - Italy),

<sup>5</sup>Rutgers University  
(Piscataway, New Jersey 08854 - USA),

<sup>6</sup>LPNHE, University of Paris 6-7 and CNRS-IN2P3  
(Paris - France),

## Abstract

The study of processes containing  $\tau$  leptons in the final state will play an important role at Tevatron Run II. Such final states will be relevant both for electroweak studies and measurements as well as in searches for physics beyond the Standard Model. The present paper discusses the physics opportunities and challenges related to the implementation of new set of triggers able to select events containing tau candidates in the final state. We illustrate, in particular, the physics capabilities for a variety of new physics scenarios such as supersymmetry (SUSY), SUSY with  $\mathcal{RP}$ -parity violation, with Bilinear parity violation or models with the violation of lepton flavor. Finally, we present the first Run II results obtained using some of the described tau triggers.

physics beyond the Standard Model. In order to be able to select such events, specific dedicated tau trigger systems have been designed and implemented in the Collider Detector at Fermilab (CDF-II) experiment. This article discusses the physics opportunities and challenges related to the implementation of this set of  $\tau$  triggers. The paper is organized as follows: first we review the major CDF-II upgrades; then we discuss which are the typical signatures for a tau lepton at Tevatron; next follows an illustration of the tau Trigger architecture and the variety of physics topics addressable by the Lepton Plus Track (LPT) Trigger. Finally we describe some preliminary results based on data samples collected by using the LPT trigger.

## 1. Introduction

Since the discovery of the  $\tau$  lepton in 1975 [1] the knowledge about its properties and interactions has improved drastically. At present most of the tau physics is shifting towards high precision measurements involving the determination of the  $\tau$  static properties, the investigation of the lepton universality and tests of the Lorentz structure of  $\tau$  decays. The tau physics program at Tevatron collider is predominantly focused on accessing processes containing taus [2].

The study of events with  $\tau$  leptons in the final state will play an important role in Tevatron Run II, both for electroweak studies and measurements both for searches for

## 2. The CDF-II Detector

CDF-II is a 5000 ton multi-purpose particle physics experiment [3] dedicated to the study of proton-antiproton collisions at the Fermilab Tevatron collider. It was designed, built and operated by a team of physicists, technicians and engineers that by now spans over 44 institutions and includes, approximately, more than 500 members. The history of the experiment goes back over 20 years. The CDF detector has been recently upgraded [4] in order to be able to operate at the high radiation and high crossing rate of the Run II Tevatron environment. In addition, there have been several upgrades to improve

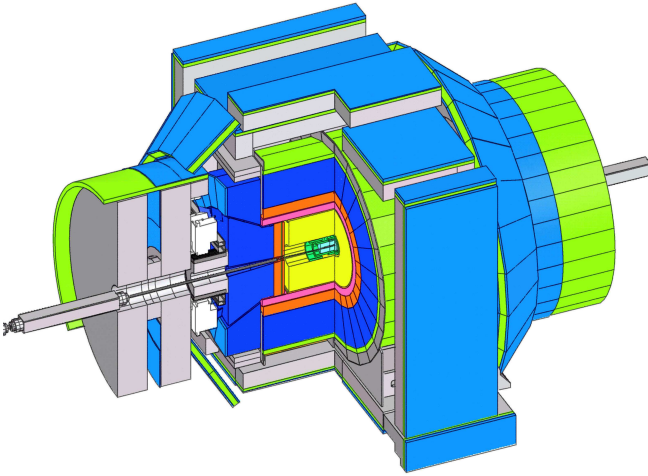


Figure 1: An overview of the Collider Detector at Fermilab (CDF) in its Run II configuration (CDF-II).

the sensitivity of the detector to specific physics tasks such as heavy flavor physics, Higgs boson searches and many others. Figure 1 shows an isometric cutaway view of the final configuration of the CDF-II detector. The central tracking volume of the CDF experiment has been replaced entirely with new detectors (see Figure 2), the central calorimeters has not been changed. These upgrades can be summarized as follows:

A new **Silicon System** done of 3 different tracking detector subsystems:

**Layer00** – a layer of silicon detectors installed directly on the beam pipe to increase impact parameter resolution.

**Silicon Vertex Detector (SVX II)** – to meet new physics goals, a central vertexing portion of the detector called SVX II was designed. It consists of double-sided silicon sensors with a combination of both 90-degree and small-angle stereo layers. The SVX II is nearly twice as long as the original SVX and SVX' (96 cm instead of 51 cm), which were constrained to fit within a previous gas-based track detector (CTC) used to locate the position of interactions along the beam line. SVX II has 5 layers instead of 4 of the previous silicon detector and it is able to give 3-dimensional information on the tracks at trigger level.

**Intermediate Silicon Layer (ISL)** is a large radius ( $R = 29$  cm) silicon tracker with a total active area of  $\sim 3.5$  m<sup>2</sup>. It is composed of 296 basic units, called ladders, made of three silicon sensors bonded together in order to form one electric unit. The ISL is located

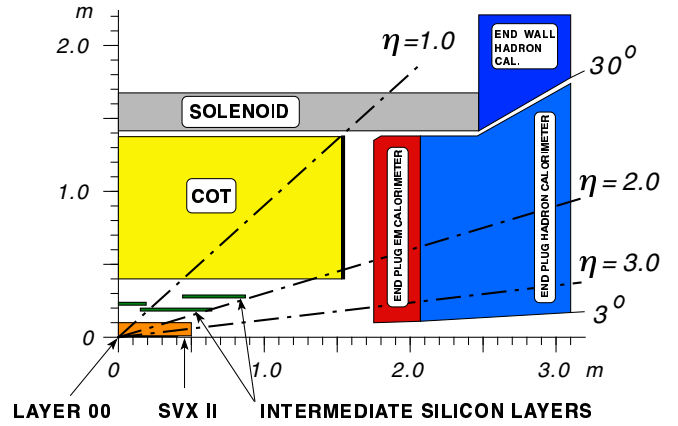


Figure 2: A cutaway view of one quadrant of the inner portion of the CDF-II detector showing the tracking region surrounded by the solenoid and endcap calorimeters.

between the Silicon Vertex Detector and the Central Outer Tracker. Being at a distance of  $\sim 23$  cm in the central part, from the beam-line, it increase the pseudo-rapidity reach of tracking system up to  $|\eta| < 2$ .

#### Central Outer Tracker (COT)

The COT is the new CDF central tracking chamber. It is an open cell drift chamber able to operate at a beam crossing time of 132 ns with a maximum drift time of  $\sim 100$  ns. The COT consists of 96 layers arranged in four axial and four stereo superlayers. It also provides  $dE/dx$  information for particle identification.

#### Time-of-Flight Detector (TOF)

New scintillator based Time-of-Flight detector has been added using a small space available between COT and solenoid. With its expected 100 ps time-of-flight resolution, the TOF system will enhance the capability to tag charged kaons in the  $P_T$  range from  $\sim 0.6$  to few GeV/c as requested from the  $B$  physics program.

#### Plug Calorimeter

A new scintillating tile plug calorimeter has been realized in order to have a good electron identification up to  $|\eta| = 2$ .

**Muon system** has also been upgraded: the coverage in the central region has been almost doubled.

A new **Data Acquisition System (DAQ)** has been

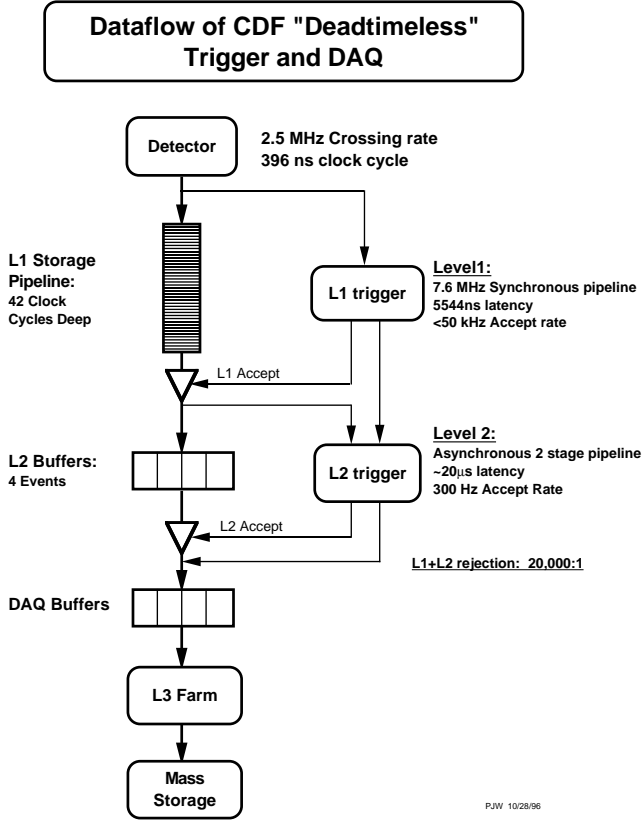


Figure 3: Data flow of CDF-II Trigger and Data Acquisition architecture.

adapted to short bunch spacing of 132 ns. It is capable to record data with event size of the order of 250 KB and permanent logging of 20 MB/s.

### 3. The CDF-II Trigger System

The CDF-II trigger system has been completely rebuilt for Run II needs. The present architecture as well as the previous one has a three-level structure, that is used to reduce the 7.6 MHz nominal crossing rate to 50 Hz maximum written to tape. Using a pipelined and buffered system, the trigger is designed to be "deadtimeless". The structure of the trigger is flexible and programmable in order to respond to changing beam conditions or physics goals. Level 1 (L1) uses custom designed hardware to find physics objects with a subset of the detector information and makes a decision based on simple counting of these objects: for example,  $\mu$  or  $e$

with  $P_T > 6 \text{ GeV}/c$ . The most significant upgrade in the L1 trigger for Run II is the addition of track finding: a new fast trigger processor, called eXtremely Fast Trigger (XFT)[7] find tracks in the central drift chamber (COT) in the  $r$ - $\phi$  plane with a resolution of  $\delta P_T/P_T > 1.6 \%$  and  $\delta\phi = 4 \mu\text{rad}$  in  $2.7 \mu\text{sec}$  after a collision. The XFT also matches tracks to muon stubs or calorimeter towers, and the Level 1 decision is generated in  $4 \mu\text{s}$  with accept rate about 50 kHz. Level 2 (L2) operates after detector readout and has an accept rate in the range 200 to 300 Hz. All the information used in the Level 1 decision is available to the Level 2 system, but with higher precision. Track collection available at Level 2 is 2-dimensional and includes tracks with  $P_T > 1.5 \text{ GeV}/c$ . In addition, jet reconstruction is made by a Level 2 cluster finder. The Level 3 (L3) trigger benefits of the full detector resolution including 3-D track reconstruction and tight matching of tracks to calorimeter and muon-system information. Its algorithm structure is based on the CDF offline analysis software and is used to reconstruct events in a processor farm with a final accept rate of 50 to 70 Hz.

### 4. Tau Identification

Tau leptons decay predominantly into charged and neutral hadrons as showed in Table 1. Hadronic decays happen with a total branching ratio that is  $\sim 64\%$ . There is, always, at least, one  $\nu$  in the final state. This kind of  $\tau$  decays have the distinct signature of a narrow isolated jet with low charged track multiplicity and low visible mass ( $M_{\text{visible}} < M_\tau$ ). Taus decay also leptonically with a branching ratio that is:  $\mathcal{BR}(\tau \rightarrow \nu e) \sim 18\%$  for the electron channel and  $\mathcal{BR}(\tau \rightarrow \nu \mu) \sim 17\%$  for the muon channel. The presence of at least one neutrino, in all possible tau decay, implies that energy cannot be measured directly. However, the direction of a tau can be obtained from the observed decay products as the energy of such decay products is large compared to the mass. There is also another practical correlation between the tau visible energy and the cone size of the tracks. The bigger is the energy of the tau lepton, the smaller will be the cone size defined by these escaping tracks. As a side effect, taus will appear, in the rest frame of the CDF-II detector, as narrow isolated jets, with low track multiplicity. Then taus coming from  $Z^0$  or  $W$  decay show up to be ultra-relativistic and to have mainly one or three prong's track multiplicity. Then to enhance, at trigger level, the separation of tau-jet signal from the generic  $W$  + jets background, an isolation cone cut have to be applied. The basis of our triggers is, therefore, a  $\tau$ -cone

$\tau \rightarrow e\nu\nu_\tau$	$\approx 18\%$	$\mathcal{BR}$ , univ, Michel
$\tau \rightarrow \mu\nu\nu_\tau$	$\approx 17\%$	$\mathcal{BR}$ , univ, Michel
$\tau \rightarrow \pi\nu, K\nu_\tau$	$\approx 12\%$	$\mathcal{BR}$ , univ
$\tau \rightarrow \pi\pi\nu_\tau$	$\approx 25\%$	$\mathcal{BR}$ , $\rho, \rho'$ , CVC, $\Pi$
$\tau \rightarrow K\pi\nu_\tau$	$\approx 1.4\%$	$\mathcal{BR}$ , $K^*, K^{*'}$
$\tau \rightarrow 3\pi\nu_\tau$	$\approx 18\%$	$\mathcal{BR}$ , $a_1, a_1'$ ,
$\tau \rightarrow K\pi\pi\nu_\tau$	$\approx 0.8\%$	$\mathcal{BR}$ , $K_1, K_{1b}, W-Z^0$
$\tau \rightarrow 4\pi\nu_\tau$	$\approx 5\%$	$\mathcal{BR}$ , $\rho'$ , CVC
$\tau \rightarrow \text{rare}$	$\approx 2\%$	$5\pi, 6\pi, \eta\pi\pi, \dots$
$\tau \rightarrow \eta\pi\nu, b_1\nu_\tau$	$\ll 1\%$	$2^{nd}$ -class currents
$\tau \rightarrow \text{forbidden}$	$\ll 1\%$	neutrinoless decays

Table 1: Main decay modes of the  $\tau$  lepton [5].

algorithm for the reconstruction of hadronic  $\tau$  decays. To build the  $\tau$ -cone object, we start with a narrow calorimeter cluster above a suitable  $E_T$  threshold, which determines the direction for searching the seed track with momentum above certain  $P_T$ .

The region within an angle  $\Theta_{\text{Sig}}$  from the seed track direction is used to define a cone of tracks to be associated with the candidate  $\tau$  lepton. The region between  $\Theta_{\text{Sig}}$  and  $\Theta_{\text{Iso}}$  defines the isolation cone, and we require that no tracks with  $P_T$  higher than a fixed low threshold have to be found in the isolation cone. At trigger level,  $\Theta_{\text{Sig}}$  and  $\Theta_{\text{Iso}}$  have values of  $10^\circ$  ( $0.1745 \text{ rad}$ ), and  $30^\circ$  ( $0.5235 \text{ rad}$ ):  $N_{\text{track}}^{10^\circ-30^\circ} = 0$ . At L2, these angles are available in the  $r$ - $\phi$  plane, while at L3 it is possible to use 3-dimensional angles. In offline tau reconstruction we allow the  $\tau$  cone to shrink with the increase of the visible energy to take into account the Lorentz non invariance of fixed cone clustering algorithm.

## 5. The CDF-II Tau Triggers

The CDF-II  $\tau$  Triggers are a set of Triggers integrated into all 3 levels of the general CDF-II Trigger system. At the present CDF-II has five different  $\tau$  triggers operating:

- Central Muon Plus Track;
- CMX Muon Plus Track;
- Central Electron Plus Track;
- Di-Tau Trigger;
- Tau +  $\cancel{E}_T$ ;

These Triggers were installed in the CDF-II trigger tables in January 2002. Naturally, the design of these triggers has evolved in time. At the present they are all working properly collecting data in stable, non pre-scaled way. Below we will describe in more details the basic characteristics of each of the LPT triggers.

## 6. The Lepton Plus Track Triggers

The Lepton Plus Track Trigger is a class of low momentum dilepton triggers able to select events containing charged leptons, including  $\tau$ 's, in the final state [6].

As taus in  $\sim 35\%$  of cases promptly decay into leptons and the rest of times in hadrons, then dilepton events, where both leptons are  $\tau$ 's, can be identified by accessing both purely leptonic di- $\tau$  decays:  $\tau_e \tau_e$ ,  $\tau_e \tau_\mu$  or mixed leptonic-hadronic di- $\tau$  decays:  $\tau_e \tau_h$  or  $\tau_\mu \tau_h$ . Then the full accesible final states are:  $ee$ ,  $e\mu$ ,  $e\tau_h$ ,  $\mu\mu$ ,  $\mu\tau_h$ . Hadronic decays of taus result in jets that must be distinguished from jets arising from QCD processes. In this case the “ $\tau$ -jetiness” is ensured by the isolation criteria applied around the second track at Level 3. As a corollary, this prevents the track from being a product of a light quark or heavy flavored quark jet.

Because of the XFT track requirement for both the lepton and the second track, this trigger is restricted to operate in the central region of the CDF-II detector. Extending its geometrical acceptance will represent a probable future upgrade.

### 6.1 Central Electron Plus Track Trigger

The selection of the Electron Plus Track Trigger starts at L1, by requiring a single EM tower with transverse energy ( $E_T$ ) above 8 GeV and an associated XFT

<b>Level 1</b>	<u>Electron Object</u> (EM Shower with XFT track) $E_T(e) > 8 \text{ GeV}$ , $E_{\text{HAD}}/E_{\text{EM}} < 1/8$ Associated XFT track $P_T^{\text{XFT}} \geq 8.34 \text{ GeV}/c$
<b>Level 2</b>	<u>Electron Object</u> $E_T(e) > 8 \text{ GeV}$ , $E_{rm\text{XCES}} > 2 \text{ GeV}$ $E_{\text{HAD}}/E_{\text{EM}} < 1/8$ <u>2nd XFT track</u> XFT track $P_T^{\text{XFT}} > 5.18 \text{ GeV}/c$ $ \Delta\phi(e, \text{track})  > 10^\circ$
<b>Level 3</b>	<u>Electron Object</u> (electron matched to EM Shower) $ \Delta z_{\text{CES}}  < 8 \text{ cm}$ , $\chi_{\text{CES}}^2 < 20$ $E_T > 8 \text{ GeV}$ , $P_T > 8 \text{ GeV}/c$ <u><math>\tau</math>-cone track requirements</u> $P_T \geq 5 \text{ GeV}/c$ , $ \eta  \leq 1.5$ $N_{\text{track}}^{10^\circ-30^\circ} = 0$ (with $(P_T > 1.0 \text{ GeV}/c$ and $ \Delta z  < 15 \text{ cm}$ ) <u>Electron + <math>\tau</math>-cone track Object</u> $ \Delta z_0  =  z_0(e) - z_0(\text{trk})  \leq 15 \text{ cm}$ , $ \Delta R  > 0.175$

Table 2: Central Electron Plus Track Trigger.

track with  $P_T > 8 \text{ GeV}/c$ . At Level 2 the electron identification cuts are tightened by requiring the CES  $E_T > 2 \text{ GeV}$ . In addition, L2 demands a second XFT track of  $5 \text{ GeV}/c$ . Level 3 refines these conditions and further more requires a charged track isolation around the track reconstructed at L3. Table 2 gives L1, L2 and L3 definitions for the Electron Plus Track Trigger. The current L3 average cross-section for the Central Electron Plus Track Trigger is  $\sim 29 \text{ nb}$ .

### 6.2 Central Muon Plus Track Trigger

The selection of a muon plus track candidate starts at L1 by requiring the presence of hits in the CMP chambers associated with a CMU stub with  $P_T > 6.0 \text{ GeV}/c$  that matches an XFT track. L2, contrary to the electron case, is at present just an "auto-accept" as the L2 muon system is not currently operational. Then L3 requires another track of at least  $5 \text{ GeV}/c$  and with an isolation compatible with the one of a hadronically decaying  $\tau$ . The current average cross-section for the Central Muon Plus Track Trigger is  $\sim 16 \text{ nb}$ .

### 6.3 CMX-muon Plus Track Trigger

The Central Muon eXtension (CMX) is a set of drift tubes sandwiched between two scintillator layers (CSX) realized to give a further coverage for the muons in the  $\eta$  range between 0.6 and 1. The CMX Plus Track Trigger then is the a kind of Muon Plus Track Trigger in the pseudorapidity region:  $0.6 < |\eta| < 1.0$ .

## 7. Other Tau Triggers

### 7.1 Di-Tau Trigger

At L1 this trigger requires 2 calorimeter towers with  $E_T > 5 \text{ GeV}$  and 2 matching XFT tracks with  $P_T > 6 \text{ GeV}/c$ , with an angle of  $\phi > 30^\circ$  between them. Level 2 checks for calorimeter clusters with  $E_T > 10 \text{ GeV}$  and imposes a track isolation cut. At L3, using the full reconstruction code, 2  $\tau$  candidates with a seed track with  $P_T > 6 \text{ GeV}/c$ , originating from the same vertex:  $|\Delta z| < 10 \text{ cm}$ , are required. At the present the average cross section for this trigger is  $\sim 12 \text{ nb}$ .

### 7.2 Tau Plus $E_T$ Trigger

Another Tau Trigger that is not part of the LPT trigger is the Tau Plus  $E_T$  Trigger. It requires the presence of

<b>Level 1</b>	<u>Muon Object</u> (muon stub with XFT track) $P_T(\mu)^{stub} > 6 \text{ GeV}/c$ Associated XFT track $P_T^{XFT} \geq 4.09 \text{ GeV}/c$
<b>Level 2</b>	<u>Muon Object</u> Auto Accept <u>2nd XFT track</u> XFT track $P_T^{XFT} > 8.0 \text{ GeV}/c$
<b>Level 3</b>	<u>Muon Object</u> $ \Delta x_{CMU}  < 15.0 \text{ cm},  \Delta x_{CMP}  < 20.0 \text{ cm}$ $P_T > 8 \text{ GeV}/c$ <u><math>\tau</math>-cone track requirements</u> $P_T \geq 5 \text{ GeV}/c,  \eta  \leq 1.5$ $N_{track}^{10^\circ-30^\circ} = 0$ (with $P_T > 1.5 \text{ GeV}/c$ and $ \Delta z  < 15 \text{ cm}$ ) <u>Muon + <math>\tau</math>-cone track object</u> $ \Delta z_0  =  z_0(\mu) - z_0(trk)  \leq 15 \text{ cm},  \Delta R  \geq 0.175$

Table 3: Central Muon Plus Track Trigger.

missing transverse energy  $\cancel{E}_T > 10 \text{ GeV}$  at L1. At L2 this request is increased to a value of  $\cancel{E}_T > 20 \text{ GeV}$  and a calorimeter cluster with an isolated track with  $P_T > 10 \text{ GeV}/c$  is required. This is followed by the full event reconstruction at Level 3, requiring the presence of at least one  $\tau$  candidate having a seed track  $P_T > 4.5 \text{ GeV}/c$ . At the present, the Tau Plus  $\cancel{E}_T$  Trigger average cross section is  $\sim 5 \text{ nb}$ .

## 8. Physics topics addressable by the LPT trigger

The main goal of this section is to show possible applications of the LPT trigger [6]. Low  $P_T$  dileptons are a basic element for many and very important signatures, both in SM physics and in searches for physics beyond the SM. The main goal of this section is then to give a mini-review of the possible applications of the LPT Trigger. As we saw, our trigger is a class of low momentum dilepton triggers able to access the following final states:  $ee, e\mu, e\tau_h, \mu\mu$  and  $\mu\tau_h$ .

### 8.1 Standard Model Physics

#### 8.1.1 Drell-Yan Production

The Drell-Yan (DY) process can be accessed for all lepton pairs produced down to rather low  $P_T$  and  $E_T$ . It includes all charged dileptons:  $ee, \mu\mu, \tau\tau$ . The interest

to study such production goes beyond the study of the Drell-Yan process itself as this signature is also typical of theories beyond the SM such as, in particular, Extra Dimension Theories. Also of interest is a study of  $Z^0 \rightarrow \tau\tau$  where one of the  $\tau$ 's decays leptonically and the other hadronically. In this respect, this trigger is quite unique to perform this measurement. This signature is crucial in the search for Higgs(es) where the Higgs decays into a pair of  $\tau$ 's as the  $Z^0 \rightarrow \tau\tau$  is a primary source of background events. The study of the  $Z^0 \rightarrow b\bar{b}$  channel is mandatory prior to the search for the  $H^0 \rightarrow b\bar{b}$ . Also this channel can be studied with the LPT trigger but only in the case where both the  $b$ 's decay semileptonically in  $e, \mu$  or  $\tau$ -leptons.

#### 8.1.2 Top Quark Physics

Another important physics topic reachable by the LPT trigger is top quark physics. After the discovery of the top-quark in Run I of the Tevatron, Run II will provide the unique opportunity to start doing top-physics both from the point of view of the SM and to study it, as a background, for many possible new phenomena. Being able to measure accurately its mass, its cross-section and its various branching ratios is fundamental. This trigger allows us to study the production of a top pair through the decay products into two charged leptons (including the  $\tau$ -lepton), thus the various channels:  $ee, e\mu, \mu\mu, e\tau, \mu\tau, \tau\tau$  can be examined. The remark on

the isolation constraint applies again here: the search for the lepton + jet signatures with jets other than  $\tau$ -jets, will be dramatically impeded with the present trigger. The LPT trigger could also contribute to the study of the single top production, especially in the case where the  $W$  decay product of the single top decays into a  $\tau$ -lepton. Furthermore, the same trigger gives the possibility to study the  $b$ -fragmentation that impacts on the top measurement. Comparing with the other triggers that are currently used for the top studies, this trigger gives a unique access to the top searches where top decays leptonically producing one or two  $\tau$ -leptons.

### 8.1.3 $W$ and $Z^0$ pairs and $H$ production

For the  $W$  or  $Z^0$  pair production, this trigger selects the signatures where both  $W$  or at least one of the  $Z^0$  decays leptonically, including  $\tau$ 's. It gives a possibility to select signatures of  $WH$  production with Higgs decaying into  $b\bar{b}$  or  $\tau^+\tau^-$ , and a  $W$  through its leptonic decay including  $\tau$ 's; the other part of the trigger signature can be used for the Higgs identification. It also serves to identify  $Z^0H$  where the  $Z^0$  decays leptonically and  $H$  decays into a  $b\bar{b}$  or a  $\tau^+\tau^-$ . Or one can look for  $Z^0H$  production with any decay for the  $Z^0$  and using the lepton + track signature to identify the Higgs. The  $b$ 's can be identified through their semi-leptonic decays and the  $\tau$ 's if both decay leptonically, or if one decays hadronically and the other one leptonically. The advantage in this case of using the LPT trigger is that it goes down to rather low  $E_T$  and  $P_T$  thresholds even for processes where the decay products have rather high  $E_T$ , it thus provides a useful overlap region between the corresponding standard process backgrounds and the signal to be looked for. It furthermore permits to study, with lower  $E_T$  and  $P_T$  samples, some systematic effects, such as fake leptons based on the same trigger selection.

## 8.2 Beyond the Standard Model

The dilepton signature is quite a fundamental signature for many exotic processes. It is also the basis signature for multilepton signatures that include at least three charged leptons in the final state. Here below we briefly describe the main physics topics addressable from the LPT trigger. For what concerns the general SUSY scenarios, it should be noticed that the  $\tau$ -enriched signature are expected to become dominant as soon as  $\tan\beta$  increases. This was one of stronger motivations to develop such kind of triggers.

### 8.2.1 Search for $\tilde{\chi}^\pm$ and $\tilde{\chi}^0$ associated production

LEP 200 performed impressive and rather unique work in searching for the lightest SUSY particle (LSP), namely the neutralino  $\tilde{\chi}_1^0$ , in the Minimal Extension of Supersymmetric Standard Model (MSSM) framework. Tevatron was not able to compete with LEP results because of the lack of luminosity. One of the main Run-II challenges is to overcome the LEP limits on gauginos. CDF at Run I [8] demonstrated that with a powerful tracking system, the measurement of multilepton signatures with 2 or 3 well measured leptons is an essential tool to search for chargino-neutralino production:  $p\bar{p} \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow 2 \text{ or } 3 \text{ charged leptons}$ . Thus, the LPT trigger allows to select this class of events including  $\tau$ 's in the final states.

### 8.2.2 Search $\tilde{g}$ and $\tilde{q}$ cascade decays

The higher Run II integrated luminosity together with the improved CDF-II detector performances will allow the search for gluino and squark cascade decays, otherwise non searchable as it was during the Run I. Among the interesting possibilities, there is the case where the gluino decays into a  $b$ -quark and sbottom ( $\tilde{b}$ ), followed by  $\tilde{b} \rightarrow b\tilde{\chi}_2^0$  ( $\tilde{\chi}_2^0 \rightarrow \tau\tilde{\tau}$  and  $\tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0$ ). This  $\tau$ -enriched signature will become more dominant as  $\tan\beta$  becomes larger. The final decay product of the gluino will be:  $b\bar{b}\tau\tau\tilde{\chi}_1^0$ . The  $\tau$ 's produced in this case will have relatively low  $P_T^\tau$ , which makes the LPT trigger particularly sensitive to this channel.

### 8.2.3 Search for scalar top and $\mathcal{RP}$ Violation

The search for the scalar partner of the top quark  $\tilde{t}_1$  in the MSSM framework is generally performed looking at the  $c\tilde{\chi}^0$  or  $b\tilde{\chi}^\pm$  final state, that means essentially trying to tag the  $b$ -jet or the  $c$ -jet. In models with  $\mathcal{RP}$  Violation (RPV) the stop squark can decay to  $b\tau$  giving the following final states:  $p\bar{p} \rightarrow \tilde{t}_1 \tilde{t}_1 \rightarrow \tau_h b \tau_\ell \bar{b}$  that proof that LPT trigger is instrumental in this case. As studied in Run 1 and LEP 200, various  $\mathcal{RP}$  violated SUSY scenarios lead to enriched multilepton signatures. For all these cases, this trigger will be quite useful. In addition, the fake leptons that are a crucial issue for these searches can be studied with the same triggered sample of data, and thus reduce systematic effects.

### 8.2.4 Search for non-SM top quark decays

One of the major issues of Tevatron will be to understand the real nature of top quark production and decay. Top quark production, be it  $t\bar{t}$  or single top, is an



ideal place where to look for new physics. If there is any new physics associated with the generation of mass, it may be more apparent in the top quark sector than with any of the other lighter, known, fermions. Many models predict new particles or interactions that couple preferentially to the third generation and in particular to the top quark. These models extend the strong, hypercharge or weak interactions in such a way that, at some scale, the new groups spontaneously break into their SM subgroup:  $SU(3)_h \times SU(3)_l \rightarrow SU(3)_C, SU(2)_h \times SU(2)_l \rightarrow SU(2)_W$ , and  $U(1)_h \times U(1)_l \rightarrow U(1)_Y$ , where  $h$  represents the third (heavy) generation and  $l$  the first two (light) generations. As a result, one would expect production rate and kinematic distributions of the decay products to differ from the SM predictions. The SM predicts  $BR(t \rightarrow bW) > 0.998$ . Other decays allowed in the SM are not only rare, but also too difficult to disentangle from backgrounds to be observed in the future. Nevertheless, one must try to be sensitive to all conceivable signatures of top quark decay, as some can be enhanced by several orders of magnitude in scenarios beyond the SM. Here we highlight some scenarios, with interesting theoretical motivations, in the rich of Tevatron Run 2, that will get a relevant advantage of the LPT trigger.

### 8.2.5 Search for SUSY decays of top

The CDF experiment has already searched, during the Run I, for events of this type where the SM top decay proceeds as  $t \rightarrow Wb \rightarrow \ell\nu_\ell b$  ( $\ell = e, \mu$ ), while the SUSY decay of the other top proceeds as  $t \rightarrow \tilde{t}_1 \tilde{\chi}_1^0 \rightarrow b \tilde{\chi}_1^+ \tilde{\chi}_1^0 \rightarrow b q_1 \bar{q}_2 \tilde{\chi}_1^0 \tilde{\chi}_1^0$  setting a 95% C.L. limit on  $BR(t \rightarrow \tilde{t}_1 \tilde{\chi}_1^0)$  as function of  $m_{\tilde{t}_1}$ ,  $m_{\tilde{\chi}_1^\pm}$  and  $m_{\tilde{\chi}_1^0}$  [12]. The LPT trigger will allow us to access also final states containing  $\tau$ 's, making possible to increase the sensitivity on the branching ratio  $BR(t \rightarrow \tilde{t}_1 \tilde{\chi}_1^0)$ .

### 8.2.6 Top decays in BRPV

Another class of models that will be possible to investigate by using the LPT trigger are the Bilinear  $\mathcal{R}_P$  Violation (BRPV) [13, 14, 15, 16]. These models are well-motivated theoretically as they arise as effective truncations of models where  $R$ -Parity is broken spontaneously [17] through right handed sneutrino vacuum expectation values (vev)  $\tilde{\nu}^c = v_R \neq 0$ . In the BRPV models the charginos mix with the charged leptons, the neutralinos with neutrinos, and the charged sleptons with the charged Higgs boson [13, 14, 15]. Therefore, the top can

have additional decay modes:

$$t \rightarrow \tilde{\tau}_1^+ b, \quad t \rightarrow \nu_\tau \tilde{t}_1, \quad t \rightarrow \tau^+ \tilde{b}_1$$

In every case the various decay modes lead to cascade decays:

$$\begin{aligned} t \rightarrow \tilde{\tau}_1^+ b & \rightarrow \tau^+ \nu_\tau b \\ & \rightarrow \tau^+ \tilde{\chi}_1^0 b \rightarrow \tau^+ f \bar{f} \nu_\tau b \\ & \rightarrow \tau^+ f \bar{f}' \tau^\pm b \\ & \rightarrow \nu_\tau \tilde{\chi}_1^+ b \rightarrow \nu_\tau f \bar{f}' \nu_\tau b \\ & \rightarrow \nu_\tau f \bar{f} \tau^+ b \\ & \rightarrow csb \\ t \rightarrow \tau^+ \tilde{b}_1 & \rightarrow \tau^+ \nu_\tau b \\ & \rightarrow \tau^+ \tilde{\chi}_1^0 b \rightarrow \tau^+ f \bar{f} \nu_\tau b \\ & \rightarrow \tau^+ f \bar{f}' \tau^\pm b \end{aligned}$$

In nearly all cases there are two  $\tau$ 's and two  $b$ -quarks in the final state plus the possibility of additional leptons and/or jets. Therefore,  $b$ -tagging and a good  $\tau$  identification are important for extracting these final states. The background will come mainly from the production of one or two gauge bosons plus additional jets.

### 8.2.7 Search for SUSY Higgs

The search for the lightest SUSY Higgs ( $h_0$ ) will be very similar to the case already mentioned of the SM Higgs search. The difference can be in an enhanced rate in particular for the case where the Higgs decays into a  $\tau$ -pair. This trigger is quite unique for detecting  $h^0 \rightarrow \tau^+ \tau^-$  with one leptonic  $\tau$  and one hadronic  $\tau$  or both leptonic.

### 8.2.8 Search for Lepton Flavor Violating Higgs decays

Strong evidence in favor of neutrino masses and mixing, obtained in Super-Kamiokande and other neutrino experiments, opened a new epoch. Several extensions of the SM, Supersymmetric and not, assume the existence of flavor-changing couplings of a Higgs boson. Among them, the generic Two Higgs Doublet Model (THDM-III) can be taken as a representative case where  $BR(H \rightarrow \tau\mu)$  can reach values of order  $\simeq 10^{-1} - 10^{-2}$  as shown in [18]. The search for Lepton Flavor Violating (LFV) Higgs decay,  $H \rightarrow \tau\mu$ , is not only well motivated by the favorable interpretation of the  $\nu_\mu - \nu_\tau$  oscillation but also has the unique advantage to be at the same time a reachable Higgs discovery channel and a way to constrain the present loose bounds on the size of the LFV factor  $\kappa_{\tau\mu}$  by following a totally model independent search for LFV Higgs decays. Naturally this is an interesting signature for which the use of the Lepton Plus Track Trigger is mandatory.

### 8.2.9 Search for Large Extra Dimensions

Few years ago, Arkani-Hamed, Dimopoulos and Dvali (ADD) suggested that the fundamental quantum gravity scale is of the order of the Fermi scale:  $G_N = G_D/R^N$  where  $G_D$  is the microscopic Newton constant,  $N$  is the number of extra spatial dimensions, hidden, as compactified at each point of the 4-dimensional space, with a compactification radius  $R$  [19]. Present gravity experiments, with Cavendish-type setups, cannot test gravity below the mm scale. Tevatron can study gravity below this edge. As a matter of fact, the virtual exchange of graviton towers ( $G_{KK}$ ) either leads to modifications in SM cross sections and asymmetries or to new processes not allowed in the SM at the tree level. In the case of virtual  $G_{KK}$  emission, gravitons lead to apparent violation of 4-momentum as well as of the angular momentum. The impact of virtual gravitons then can be observed in processes such as:  $q\bar{q} \rightarrow G_{KK} \rightarrow \gamma\gamma$  or  $gg \rightarrow G_{KK} \rightarrow \ell^+\ell^-$  where the ADD model introduces production mechanism that can increase the cross-section [20]. The characteristic signatures of virtual graviton exchange correspond then to the formation of massive systems abnormally beyond the SM expectations. The LPT trigger gives a very relevant access to this physics as it permits to study pairs of charged leptons including  $\tau$ 's.

## 9. Preliminary results: the $Z^0 \rightarrow \tau\tau$ signal

As a prelude to any future analysis, and in order to illustrate the technique, we discuss, in this section, the first look at  $Z^0 \rightarrow \tau\tau$  events collected with the Electron Plus Track Trigger. The data used for this preliminary analysis was collected between March 2002 and January 2003, corresponding to a total integrated luminosity of  $\sim 72 \text{ pb}^{-1}$  [21]. In this case we will have one tau decaying leptonically in an electron ( $\tau_e$ ) and the other one hadronically ( $\tau_h$ ). Our analysis begins by requiring the presence of at least one good electron in the central region ( $|\eta^e| < 1.0$ ) with  $E_T \geq 10 \text{ GeV}$  and  $P_T \geq 8 \text{ GeV}/c$ . The cuts applied for the electron identification are similar to the standard CDF-II cuts for selecting inclusive high  $E_T$  central electrons. Since the second leg in the decay  $Z^0 \rightarrow ee$  can be misidentified as one prong  $\tau_h$ , we strictly remove any possible Drell-Yan  $Z^0 \rightarrow e^+e^-$  candidate event by using both calorimeter and track information. Then, we require the event to have at least one  $\tau_h$  object in the central region  $|\eta^{\tau_h}| < 1.0$  with a cluster transverse energy:  $E_T^{cluster}(\tau_h) > 20 \text{ GeV}$ . The SM backgrounds for  $Z^0 \rightarrow \tau_e\tau_h$  analysis are essentially

the QCD  $W(\rightarrow e\nu) + \text{jets}$ ,  $Z^0/\gamma^* \rightarrow e^+e^-$ ,  $WW$

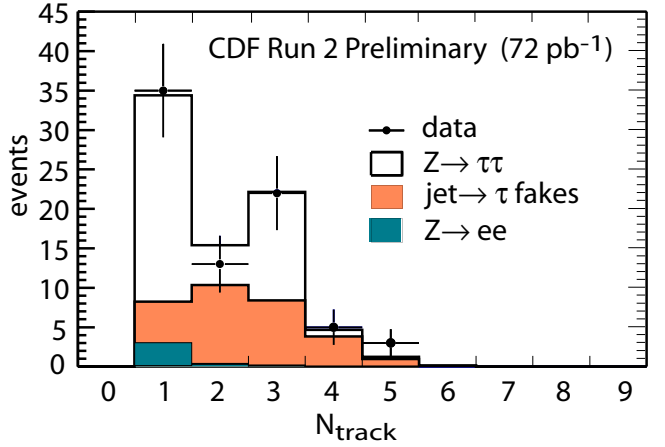


Figure 4: Track multiplicity of  $\tau$  objects in the Electron Plus Track Trigger dataset after baseline selections and  $M_T(e, \cancel{E}_T)$  and  $P_T(e, \cancel{E}_T)$  cuts. Data are shown together with the  $Z^0 \rightarrow \tau^+\tau^-$ ,  $W + \text{jets}$  and  $Z^0 \rightarrow e^+e^-$  expected contributions.

diboson production and  $t\bar{t}$  events. The QCD  $W + \text{jets}$  background is partially reduced by applying a cut on the transverse mass:  $M_T(e, \cancel{E}_T) \leq 25 \text{ GeV}/c^2$ . In fact, the  $W$  events show up in the higher mass region as in this case  $M_T(e, \cancel{E}_T)$  is the transverse mass of the  $W$ . After the  $M_T(e, \cancel{E}_T)$  cut, a significant number of QCD background events is still present in the sample. A further cut is then applied  $P_T(e, \cancel{E}_T) \geq 25 \text{ GeV}/c$ . After applying the baseline selection cuts for the electron and for the  $\tau_h$  candidate and the further cuts on  $M_T(e, \cancel{E}_T)$   $P_T(e, \cancel{E}_T)$  we end up with a sample containing 78 events. This sample is expected to consist of  $\sim 59\%$  of signal events with the rest of the background events dominated by QCD jet production. The track multiplicity associated with the  $\tau_h$  candidate found in events passing selection cuts is shown in Figure 4. We observe a clear  $\tau$  signal (1,3 prong signature) over background levels even before requiring the opposite sign charge for the electron and the  $\tau_h$ . If we define the charge of the  $\tau_h$  candidate as the sum of the track charges:  $Q(\tau_h) = \sum_{j=1}^{N_{trk}} q_j^{rk}$  it is possible to classify the sample of 78 events into same sign (SS) and opposite sign (OS) events. We are left with 47 OS events. Figure 5 shows the mass of the system containing an electron, a hadronically decaying  $\tau$  and the  $\cancel{E}_T$ . As it is possible to see, the mass distribution of the electron- $\tau_h$ - $\cancel{E}_T$  system ( $M(e + \tau_h + \cancel{E}_T)$ ) in the data is consistent with the  $Z^0 \rightarrow \tau\tau$  hypothesis. To study and collect a sample of  $Z^0 \rightarrow \tau\tau$  is an important benchmark for several reason. This sample will be fundamental in

order to calibrate the trigger system and to understand the

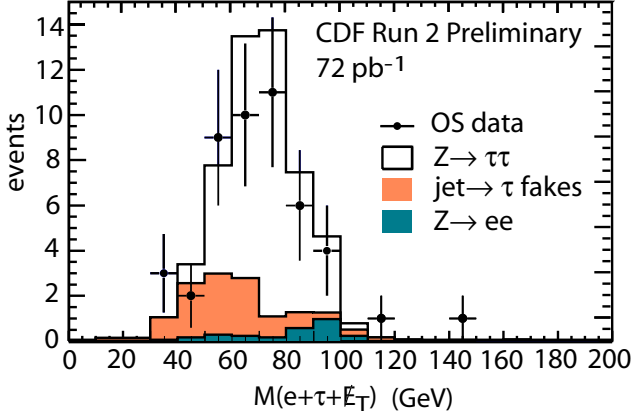


Figure 5: Mass distribution of the opposite sign  $e, \tau_h$  events in the Electron Plus Track Trigger dataset after baseline,  $M_T(e, \cancel{E}_T)$  and  $P_T(e, \cancel{E}_T)$  cuts. Data are shown together with the  $Z^0 \rightarrow \tau^+\tau^-$ ,  $W + \text{jets}$  and  $Z^0 \rightarrow e^+e^-$  expected contributions.

system global performances. On the other hand this preliminary analysis is important as the  $Z^0 \rightarrow \tau\tau$  events are one of the most significant backgrounds for many of the analysis described in the previous section.

## 10. Summary

Without any doubt  $\tau$  physics will be one of the most intriguing chapters in the Run II physics program at Tevatron. Hence, the possibility to select tau enriched samples already at trigger level open new perspectives for CDF-II experiment. In this paper we described basic ideas, implementation and performances of dedicated triggers, allowing to select events with at least one  $\tau$  candidate in the final state. With the first results on  $Z^0 \rightarrow \tau\tau$  production, obtained with one of the described trigger, we start to investigate a wide and intense area of physics searches with  $\tau$  leptons in the final state.

## 11. Acknowledgments

We thank the Fermilab staff and the technical staff of the participating Institutions for their contributions. The work described in this paper was supported by the U.S. Department of Energy and National Science Foundation; the Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of

Japan, the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung; the Korea Science and Engineering Foundation (KoSEF); the Korea Research Foundation; and the Comision Interministerial de Ciencia y Tecnologia, Spain. We thank Laszlo Jenkovszky and his staff for the kind and enjoyable hospitality.

## 12. Bibliography

1. *M.L. Perl et al.*, Phys. Rev. Lett. **35**, 2489 (1975).
2. *S. Abel et al.* [SUGRA Working Group Collaboration], FERMILAB-PUB-00-349, Mar 2000. 173pp, hep-ph/0003154.
3. *F. Abe et al.* [CDF Collaboration], Nucl. Instrum. Meth. **A271**, 387-403 (1988).
4. *F. Abe et al.* [CDF Collaboration], The CDF-II detector: Technical design report, FERMILAB-PUB-96-390-E (1996).
5. *A. Weinstein* [CLEO Collaboration], eConf **C0209101**, TU15 (2002) [arXiv:hep-ex/0210058].
6. *S. Baroiant, M. Chertok, M. Goncharov, T. Kamon, V. Khotilovich, R. Lander, T. Ogawa, C. Pagliarone, F. Ratnikov, A. Safonov, A. Savoy-Navarro, J.R. Smith, S. Tournear, E. Vataga*, "Update on the Lepton plus Track Trigger in Run 2- Definitions and Physics Goals", CDF-II Internal Note, CDF/ANAL/TRIGGER/CDFR/6325.
7. *S. Holm et al.* [CDF Collaboration], IEEE Trans. Nucl. Sci. **47**, 895 (2000).
8. *F. Abe et al.* [CDF Collaboration], Phys. Rev. Lett. **80**, 5275 (1998).
9. *F. Abe et al.* [CDF Collaboration], Phys. Rev. Lett. **74**, 2626 (1995).
10. *S. Abachi et al.* [D0 Collaboration], Phys. Rev. Lett. **74**, 2632 (1995).
11. For reviews of the MSSM and supergravity, see *H. P. Nilles*, Phys. Rep. **110**, 1 (1984); *P. Nath, R. Arnowitt, and A. Chamseddine*, Applied N=1 Supergravity, ICTP Series in Theoretical Physics Vol. I, World Scientific, Singapore, (1984); *H. Haber and G. Kane*, Phys. Rep. **117**, 75 (1985); *X. Tata*, The Standard Model and Beyond, edited by J. E. Kim, World Scientific, Singapore, 304 (1991).
12. *T. Affolder et al.* [CDF-II Collaboration], Phys. Rev. D **63**, 091101 (2001).
13. *M. A. Díaz, J. C. Romão, and J. W. F. Valle*, Nucl. Phys. **B524** 23 (1998).
14. *M. A. Díaz*, hep-ph/9711435, hep-ph/9712213; *J. C. Romão*, hep-ph/9712362; *J. W. F. Valle*, talk at PASCOS 98, hep-ph/9808292.
15. *F. de Campos, M. A. García-Jareño, A. S. Joshipura, J. Rosiek, and J. W. F. Valle*, Nucl. Phys. **B451**, 3 (1995); *A. Akeroyd, M. A. Díaz, J. Ferrandis, M. A. García-Jareño, J. W. F. Valle*, Nucl. Phys. **B529**, 3 (1998).

16. *A. S. Joshipura and M. Nowakowski*, Phys. Rev. D **51**, 2421 (1995); *T. Banks, Y. Grossman, E. Nardi, and Y. Nir*, Phys. Rev. D **52**, 5319 (1995); *F. Vissani and A. Yu. Smirnov*, Nucl. Phys. B **460**, 37 (1996); *R. Hempfling*, Nucl. Phys. B **478**, 3 (1996); *F. M. Borzumati, Y. Grossman, E. Nardi, Y. Nir*, Phys. Lett. B **384**, 123 (1996); *H. P. Nilles and N. Polonsky*, Nucl. Phys. B **484**, 33 (1997); *B. de Carlos, P. L. White*, Phys. Rev. D **55**, 4222 (1997); *E. Nardi*, Phys. Rev. D **55**, 5772 (1997); *S. Roy and B. Mukhopadhyaya*, Phys. Rev. D **55**, 7020 (1997); *A. Faesiter, S. Kovalenko, F. Simkovic*, Phys. Rev. D **58**, 055004 (1998); *M. Carena, S. Pokorski, and C. E. M. Wagner*, Phys. Lett. B **430**, 281 (1998); *M. E. Gómez and K. Tamvakis*, Phys. Rev. D **58**, 057701 (1998).
17. *A. Masiero and J. W. F. Valle*, Phys. Lett. B **251**, 273 (1990); *J. C. Romão, A. Ioannissyan, and J. W. F. Valle*, Phys. Rev. D **55**, 427 (1997).
18. *U. Cotti, L. Diaz-Cruz, C. Pagliarone and E. Vataga*, in *Proc. of the APS/DPF/DPB Summer Study on the Future of Particle Physics (Snowmass 2001)* ed. N. Graf, eConf **C010630** (2001) P102 [arXiv:hep-ph/0111236].
19. *N. Arkani-Hamed, S. Dimopoulos and G. Dvali*, Phys. Lett. B **249**, 263 (1998);
20. *N. Arkani-Hamed, S. Dimopoulos and G. Dvali*, Phys. Lett. B **436**, 257 (1998), Phys. Lett. D **59**, 257 (1999).
21. *A. Anastasov, S. Baroiant, M. Chertok, J. Conway, S. Demers, M. Goncharov, D. Jang, T. Kamon, K. Kotelnikov, V. Khotilovich, R. Lander, A. Lath, K. McFarland, P. Murat, T. Ogawa, C. Pagliarone, F. Ratnikov, A. Safonov, A. Savoy-Navarro, J.R. Smith, S. Tourneur, E. Vataga, T. Vaiculis, Z. Wan*, "Extraction of  $Z \rightarrow \tau\tau$  Signal using Run II Lepton+Track Trigger - Electron Channel", CDF-II Internal Note, CDF/ANAL/EXOTIC/CDFR/6402.